A STEREOSCOPIC DISPLAY WITH A VIBRATING MICROLENS ARRAY

Akihito Nakai, Kiyoshi Matsumoto, and Isao Shimoyama
Department of Informatics, Faculty of Engineering, The University of Tokyo
7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
Phone: +81-3-5841-6318, fax: +81-3-3818-0835
E-mail: (nakai, matsu, isao)@leopard.t.u-tokyo.ac.jp

ABSTRACT

In this paper, we demonstrate a prototype of a high-resolution stereoscopic display by vibrating a micro cylindrical lens array. This lens array is fabricated by melting photoresists and form transfer. The height and width of the cylindrical lens measured 12.5 µm and 320 µm, therefore the focal length is calculated as 1980 µm. The lens array vibrates synchronously with the changeover of images which are displayed under the lens array. The brightness is measured at several view angles, and 9 degrees-parallax is observed on condition that the amplitude and cycle of the vibration are 100 µm and 120 ms, respectively.

INTRODUCTION

If we send two different pictures to the right and left eyes with appropriate parallax, the stereoscopic effect, namely, 3D sensation of the visual image can be realized. There are several methods of the stereoscopic display, for example, lenticular, parallax barrier, integral photography and hologram [1]. Multi-view stereoscopic display is one of the methods of enabling viewers to sense the stereoscopic effect naturally. Although this method has an advantage of displaying different images depending on viewer's position, it is difficult to increase the resolution because many pixels should be placed under one cylindrical lens. Meanwhile, our experimental system projects time-series pixel data into the discrete space by vibrating a micro cylindrical lens array like a scanner (see Figure 1) [2][3]. Accordingly, one pixel has only to be aligned under its respective vibrating cylindrical lenses to keep the resolution high. If the lens array vibrates synchronously with quickly refreshed images, an ideal stereoscopic display with multi-view and high-resolution will be achieved.

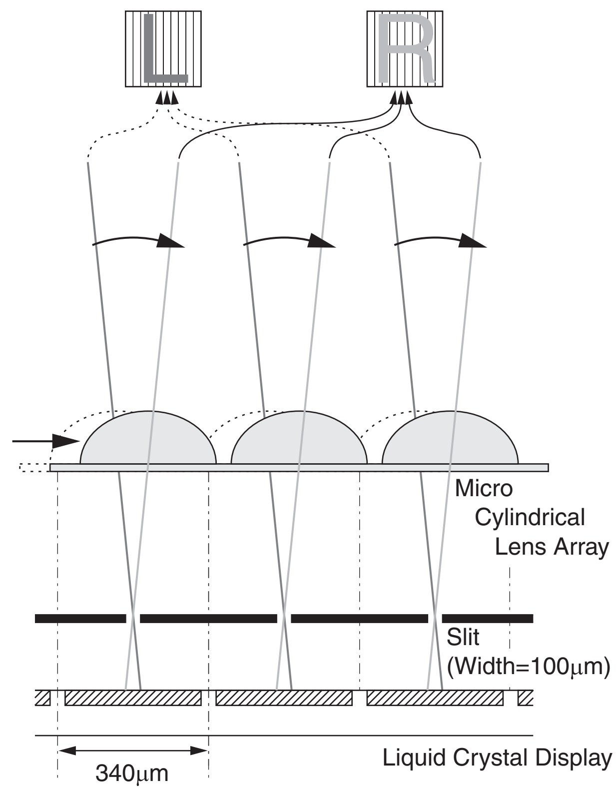

Figure 1. *A cross-section of the stereoscopic display with a vibrating micro cylindrical lens array.*

FABRICATION PROCESS

Figure 2 shows the fabrication process of the micro cylindrical lens array. A 1.2 µm-thick OFPR800 layer and a 9.0 µm-thick AZP4620 layer are spincoated on a Si wafer in sequence. We can get a long-focal-length lens by thinning the second photoresist layer, concretely, by raising the ratio of solvent in AZP4620 and speeding up the spin with coating. After exposure and development to pattern the photoresist AZP4620 cylindrically, a lens array master is made by melting the photoresist at 200 ºC [4]. In heating the Si wafer on a hotplate, the first photoresist prevents the second one from flowing out of pattern. PDMS is poured onto the lens array master and cured at 60 ºC for 50 minutes. After solidification, a PDMS film is peeled off from the lens array master and used as a mold for the micro cylindrical lens array. UV-curing adhesive

0-7803-7185-2/02/$10.00 ©2002 IEEE

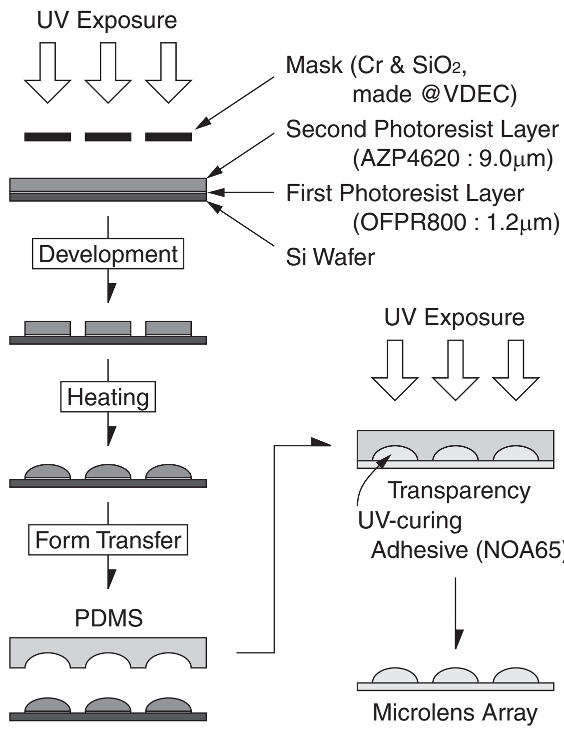

Figure 2. *The fabrication process of the micro cylindrical lens array.*

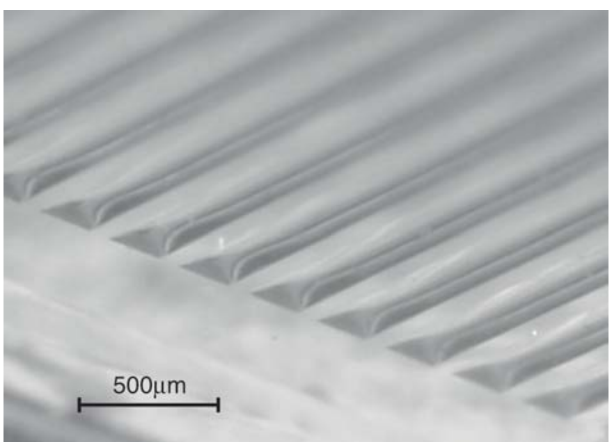

Figure 3. *A photograph of a fabricated lens array.*

NOA65 is poured into the PDMS mold. The mold is covered with a transparency, which is to be a foundation of the lens array. A photograph of a fabricated lens array is shown in Figure 3. The surface profile of a fabricated lens, which is measured by a stylus profilemeter DEKTAK, is shown in Figure 4. The height and width of the cylindrical lens measured 12.5 μm and 320 μm. Considering the scale effect, this lens width is so small that the gravity can be ignored in comparison with the surface tension. Since the surface profile of the liquid made a part of a cylinder at the field which only the

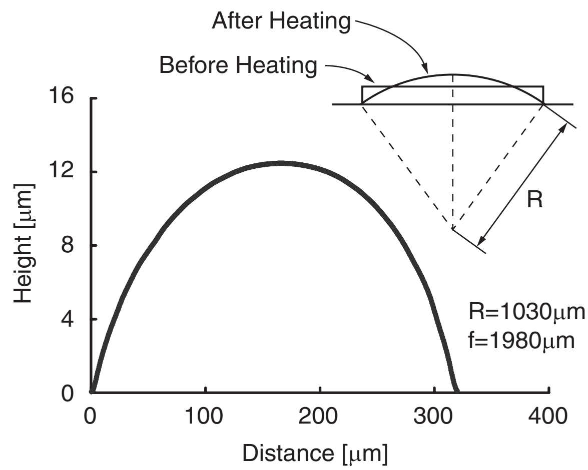

Figure 4. *The surface profile of a fabricated lens. The height and width of the cylindrical lens measured 12.5 μm and 320 μm. Then the cylindrical curvature and focal length are calculated as 1030 μm and 1980 μm, respectively.*

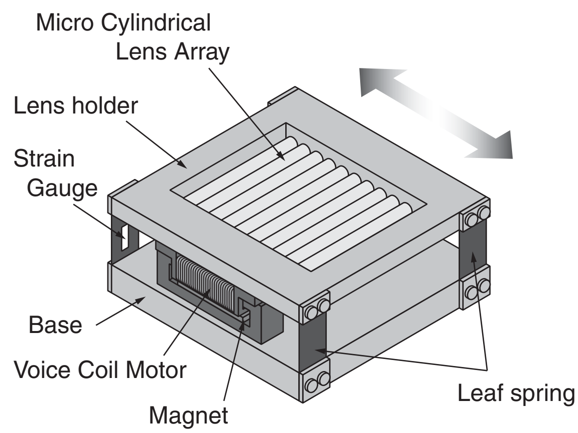

Figure 5. *A schematic view of the Rocking mechanism for micro cylindrical lens array. Natural frequency of the rocking mechanism was measured to be 15 Hz.*

surface tension affects, the focal length of the fabricated lens can be obtained by fitting a cylinder to its measured profile. Then the cylindrical curvature and focal length are calculated as 1030 μm and 1980 μm, respectively.

EXPERIMENTS

Figure 5 shows the rocking mechanism for the micro cylindrical lens array. The lens holder, where the lens array is installed, is connected to the base by 4 leaf springs at every corner. The leaf springs limit the movement of the holder in one direction. A pair of voice-coil motors

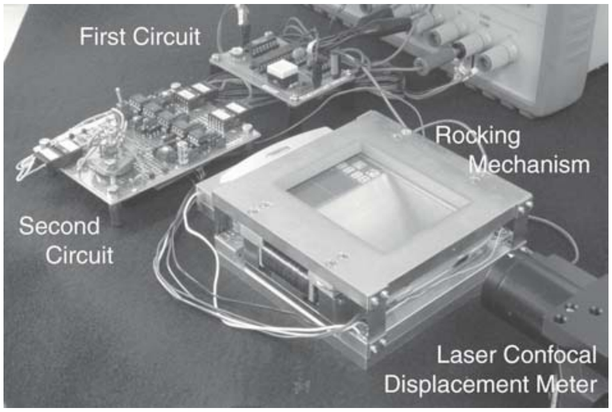

Figure 6. *A photograph of the experimental system. The LCD display (PDA) is aligned under the micro cylindrical lens array.*

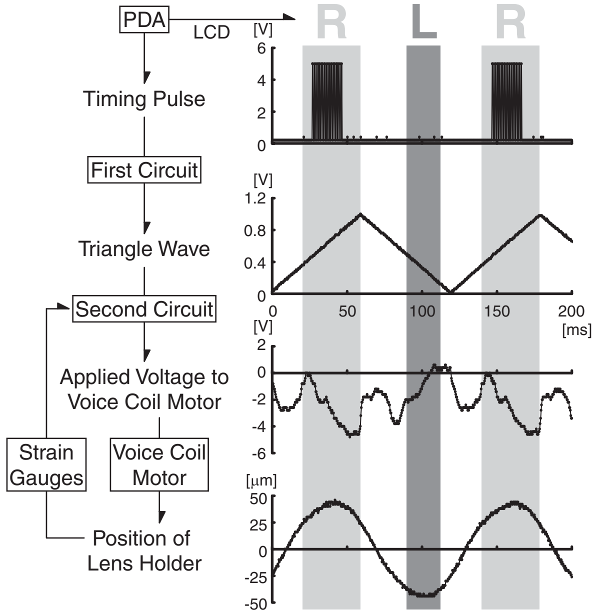

Figure 7. *The schematic of the control system and characteristic waveforms. The lens holder vibrates synchronously with two images.*

installed at both sides drives the holder. The position of the holder is detected by strain gauges glued on the surfaces of the leaf springs. Natural frequency of the rocking mechanism was measured to be 15 Hz. Sensitivity of the strain gauges was 2560 µstrain/mm. We set bandwidth of servo system to 50 Hz. A photograph of the experimental system is shown in Figure 6.

The schematic of the control system is shown in Figure 7. In our experiments, a PDA's LCD (liquid crystal display) is used. This PDA outputs a timing pulse in order to synchronize the holder's vibration with the changeover of images. The first circuit receives this timing pulse as

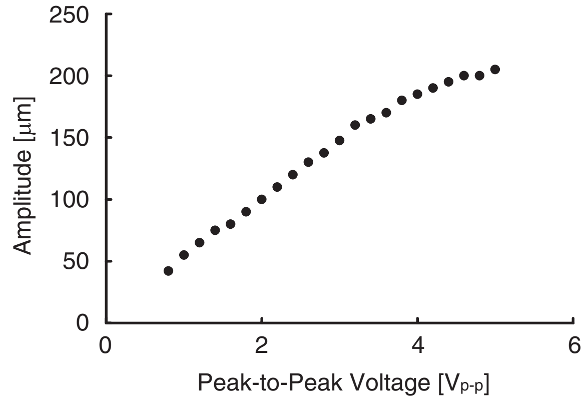

Figure 8. *The relationship between the peak-to-peak voltage of the triangle wave and the amplitude of the lens holder.*

an input, and outputs a triangle wave which is equal to the input in frequency. This triangle wave can be dephased freely, and its peak-to-peak voltage can be adjusted between 0 V and 5 V. The second circuit gets the frequency, gain and phase from the triangle wave, and outputs the signal which controls the position of the holder. As the position of the holder is fed back into the second circuit, the phase difference between the input signal and the output one is inevitable. However, the holder's vibration can be easily synchronized with the changeover of images by dephasing the triangle wave. Besides, the amplitude of the holder can be controlled by adjusting the peak-to-peak voltage of the triangle wave (see Figure 8). The points in Figure 8 are plotted linearly. But this voltage is kept below 4 V in the experiments because the vibration of the holder deviates from simple harmonic motion out of this range.

RESULTS

Figure 9 shows the relationship between the view angle and the brightness on condition that the amplitude of the holder is 100 µm and the cycle is 120 ms. The view angle is represented by θ in Figure 10. The brightness is evaluated by the following methods. In a dark room, images are shot by the digital camera whose diaphragm and shutter speed are fixed. The exposure time is set long enough in comparison with the cycle of the vibration. Next, obtained images are converted to gray scale images, and the brightness in certain area is averaged before sampling. As this LCD's backlight itself varies the brightness depending on the view angle, Figure 9(a) must be compensated with the basis of the brightness (see Figure 9(b)). Two measured values form the reversed phase, and such condition is appropriate to the

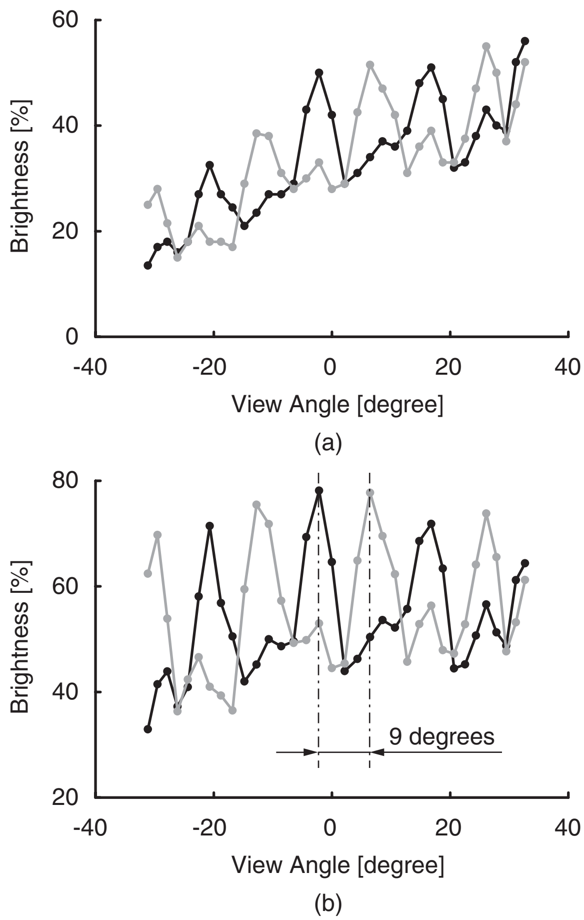

Figure 9. *The relationship between the view angle and the brightness: (a) before compensation; (b) after compensation.*

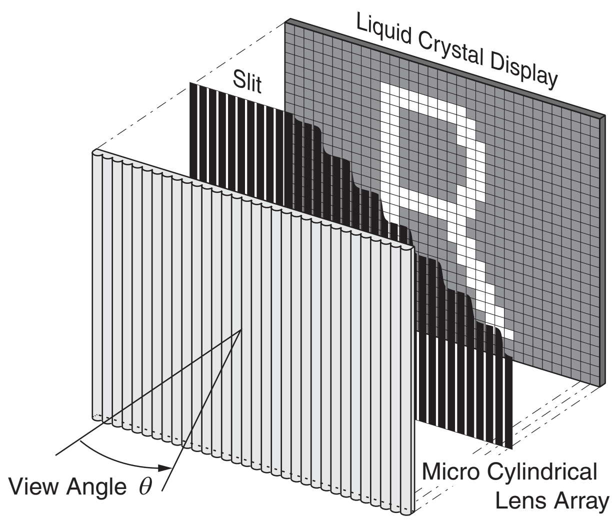

Figure 10. *The definition of the view angle θ.*

stereoscopic display. The distance between human eyes is approximately 65 mm. As the angle from peak to peak is measured to be 9 degrees in Figure 9(b), the ideal distance for stereovision is decided to be 40 cm. However, only trained viewers can sense stereoscopic effects because of the flicker caused by the low frequency of the lens array's vibration. This frequency was limited by the PDA power.

CONCLUSIONS

A micro cylindrical lens array is fabricated by the method of melting photoresist and form transfer. We achieved the condition for the stereovision by vibrating the fabricated lens array over a LCD, although it is difficult to sense stereoscopic effects for the reason of the flicker. If the frequency can be increased more and a light and thin structure, especially slit, is made by MEMS technologies, flickerless and high-resolution stereoscopic display will be achieved.

ACKNOWLEDGMENTS

Photolithography masks were fabricated using EB lithography apparatus of VLSI Design and Education Center (VDEC), the University of Tokyo.

REFERENCES

[1] H. Yamamoto, S. Muguruma, T. Sato, K. Ono, Y. Hayasaki, Y. Nagai, Y. Shimizu, and N. Nishida, "Optimum parameters and viewing areas of stereoscopic full-color LED display using parallax barrier," IEICE Transactions on Electronics, Vol. E83C, No. 10, pp. 1632-1639, 2000.

[2] T. Kimachi, R. Imaizumi, and S. Ando, "Intelligent image sensor with a vibratory mirror mimicking involuntary eye movement," 16th Sensor Tech. Symp. Dig., pp. 171-176, 1998.

[3] K. Hoshino, F. Mura, and I. Shimoyama, "Design Performance of a Micro-Sized Biomorphic Compound Eye with A Scanning Retina," Journal of Microelectromechanical Systems, Vol. 9, No. 1, pp. 32-37, 2000.

[4] Ph. Nussbaum, R. Völkel, H. P. Hertzig, and R. Dändliker, "Microoptics for Sensor Applications," Proc. European Symposium Lasers, Optics and Vision for Productivity in Manufacturing, Vol. 2783, pp. 1-9, 1996.